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A PHOTOELASTIC STUDY OF CRACKING IN MOTOR GRAIN MODELS

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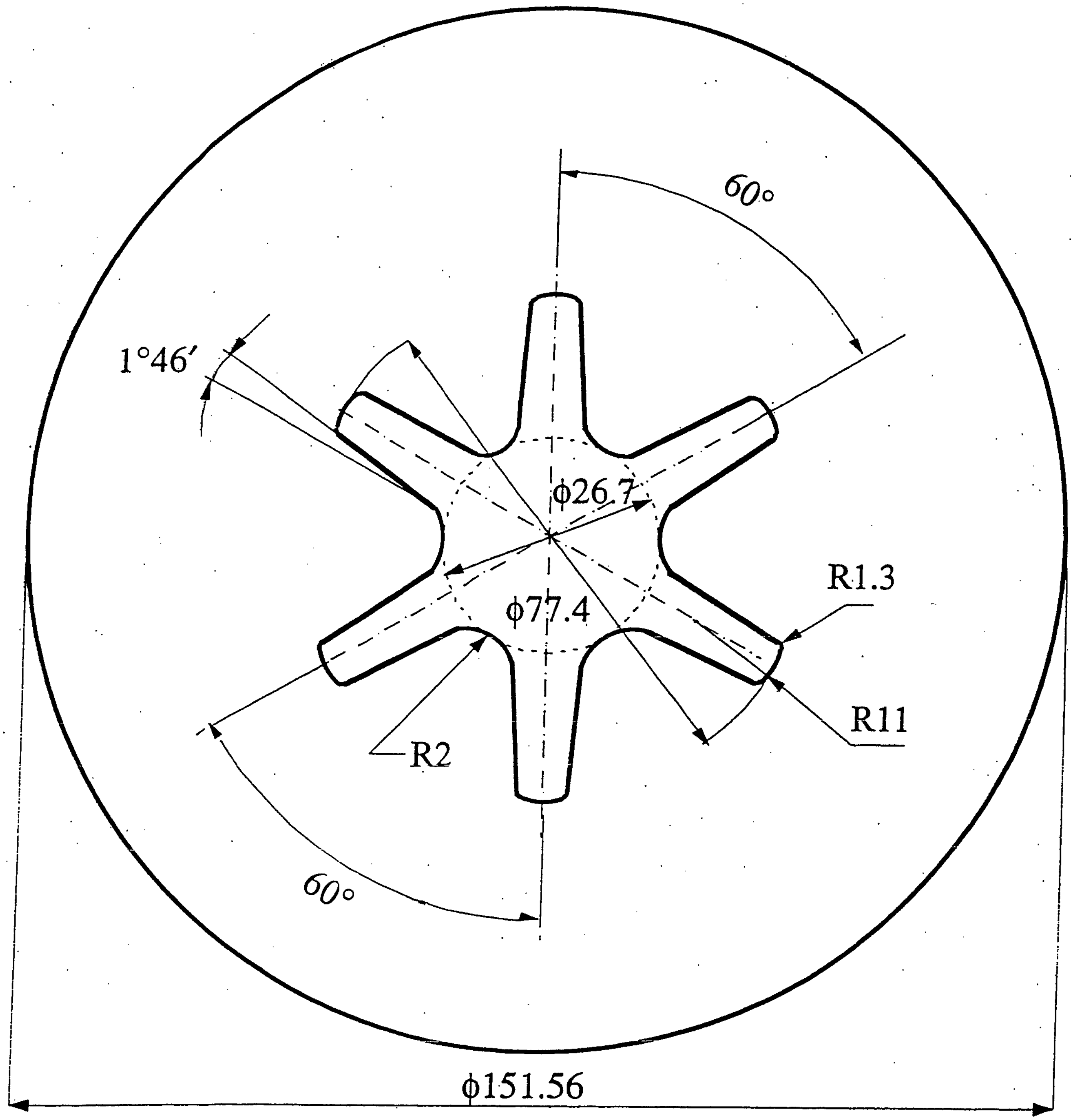
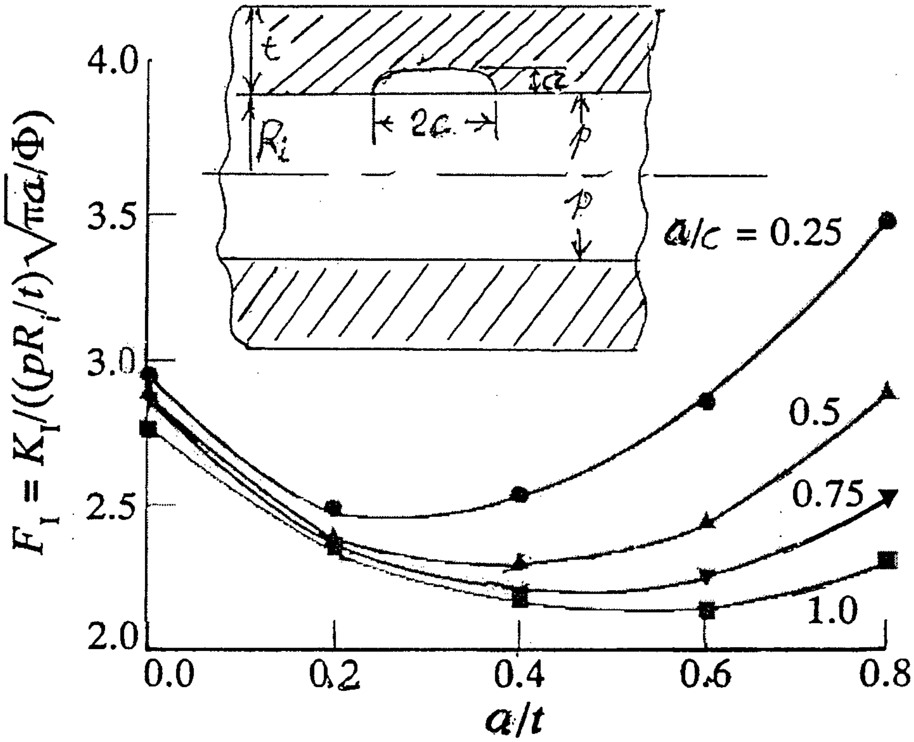
length of cylinder 376 mm



all dimensions are in mm

Figure 2: Crosssection of test models.

3

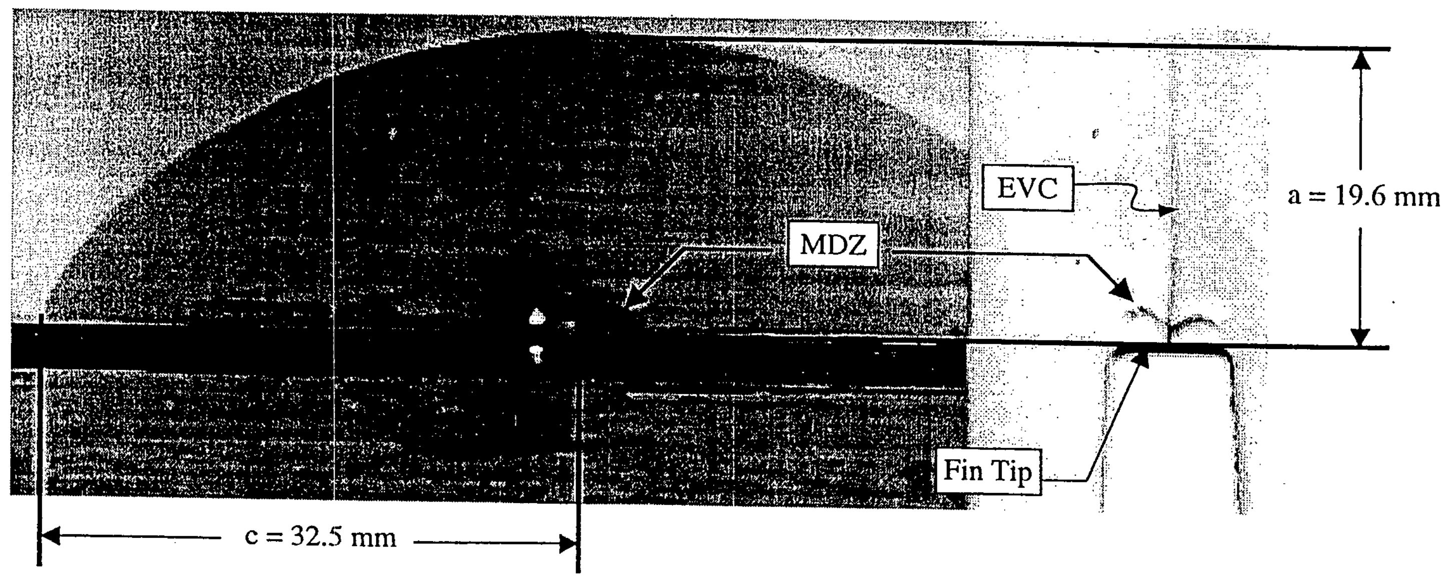


(b) $t/R_i = 1.0$

- Results from BEM showing "dish" shaped region for normalized SIF for a semi-elliptic surface crack in a pressurized thick walled cylinder.

- F_I - K_I = SIF; p = pressure, Φ = Elliptic Integral of Second Kind. See Table 1 slide.

Model 3

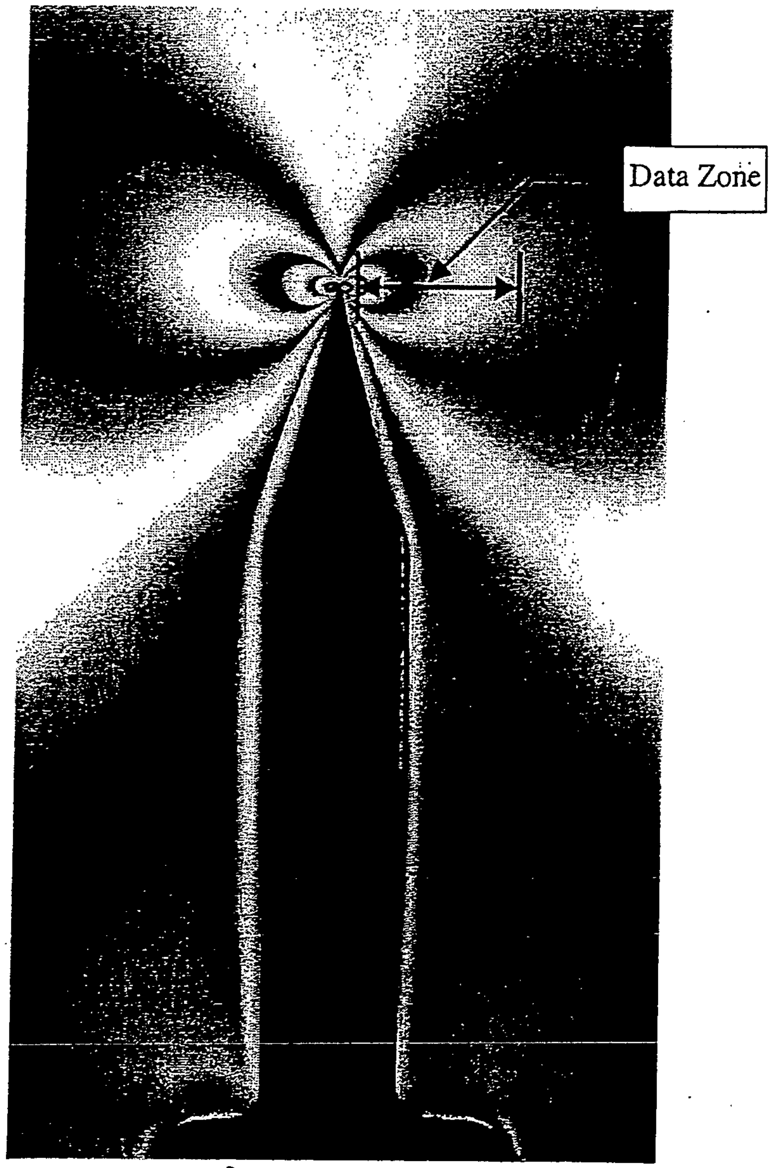


MDZ – Material Damage Zone
EVC – Edge View of Crack

Figure 3: Crack shape and fin tip location for model 3

Model 6b

Center Slice (t = 4.29 mm)



P_{sf}:	2.3×10^{-2} MPa
c_f:	175.30 mm
a_f:	19.6 mm
Data zone:	$(r_{ave})_2 - (r_{ave})_1 = 4.2635 - 0.4564 = 3.807$ mm

Figure 4: Unmultiplied fringe pattern from a 4.3mm slice from the center of the crack for Model 6 using a diffused light polariscope for a machined crack denoting location of data zone.

Mode I Algorithm For Determination of Stress Intensity Factor (SIF)

In linear elastic fracture mechanics (LEFM) using the photoelastic approach, one can begin with Mode I near tip equations (Fig. A-1)

$$\sigma_{ij} = \frac{K_I}{\sqrt{8\pi r}} f_{ij}(\theta) + \sigma^{\circ}_{ij} \quad (i.j. = n, z) \tag{A-1}$$

where K_I is the Mode I SIF, σ°_{ij} are the contribution of the nonsingular stresses in the measurement zone, and r, θ then are centered at the crack tip. The following expression is computed, in truncated form, along $\theta = \pi/2$, where fringe spreading is greatest. (Fig. A-2) Thus

$$\tau^{nz}_{max} = \frac{K_{AP}}{\sqrt{8\pi r}} = \frac{K_I}{\sqrt{8\pi r}} + \tau_0 \tag{A-2}$$

where K_{AP} is an "apparent" SIF, which includes the effect of σ°_{ij} {i.e., $\tau_0 = f(\sigma^{\circ}_{ij})$} with the singular effect in the measurement zone. The stress-optic law states that $\tau^{nz}_{max} = \frac{Nf}{2t}$, where N is the measured stress fringe order, f is the material fringe value and t the slice thickness. Thus τ^{nz}_{max} is proportional to N and may be regarded as the measured quantity together with r. By rearranging terms in Eq. A-2 and normalizing, we can obtain

$$\frac{K_{AP}\Phi}{p\sqrt{\pi a}} = \frac{K_I \Phi}{p\sqrt{\pi a}} + \frac{\sqrt{8}}{p}\tau_o \Phi \left(\sqrt{\frac{r}{a}}\right) \tag{A-3}$$

for a semi-elliptic crack where the coefficient of $\sqrt{r/a}$ is a constant, p is the internal pressure and a is the crack size. Φ is an elliptic integral which varies with the aspect ratio of the crack (a/c). Its form is approximated by $\sqrt{Q}$ where Q is given in Table I. In general, when applied to cylindrical vessels, the denominator of Eq. A-3 should be $p\frac{R_i}{t}$. However, in the present problem geometry, $R_i/t = 1$, and the R_i/t can be dropped here.

By defining the normalized SIF as

$$F = \frac{K_{AP}\sqrt{Q}}{p\sqrt{\pi a}} \tag{A-4}$$

one can plot F vs. $\sqrt{r/a}$ and locate the linear zone implied by Eq. A-3, which is the zone dominated by the stress singularity. By extending this line to the origin, the value of F is determined as shown in Fig. A.3 for Model 1.

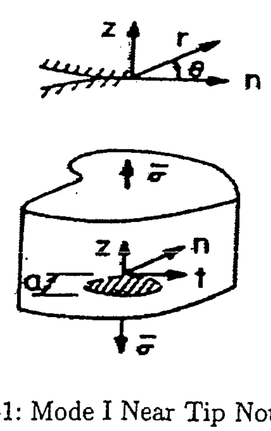


Fig. A-1: Mode I Near Tip Notation

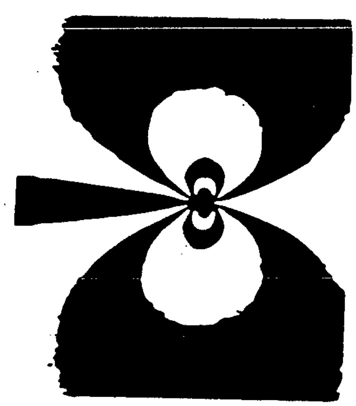


Fig. A-2: Mode I Fringe (Pattern Unmultiplied)

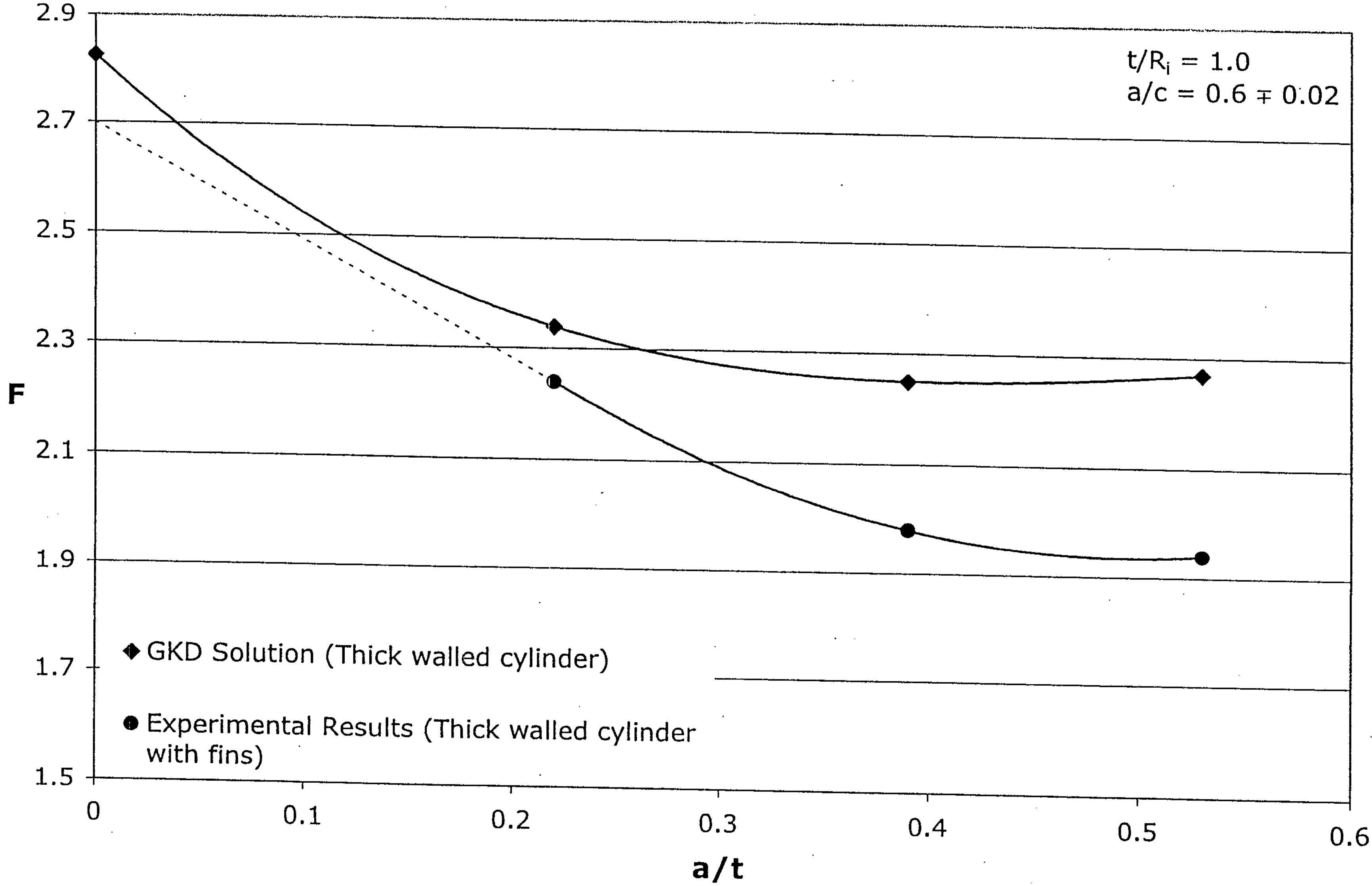


Figure 5: Comparison of experimental results for part through cracks in star finned models with same depth cracks in the pressurized cylinder models (GKD) in the central "dish bottom" region.

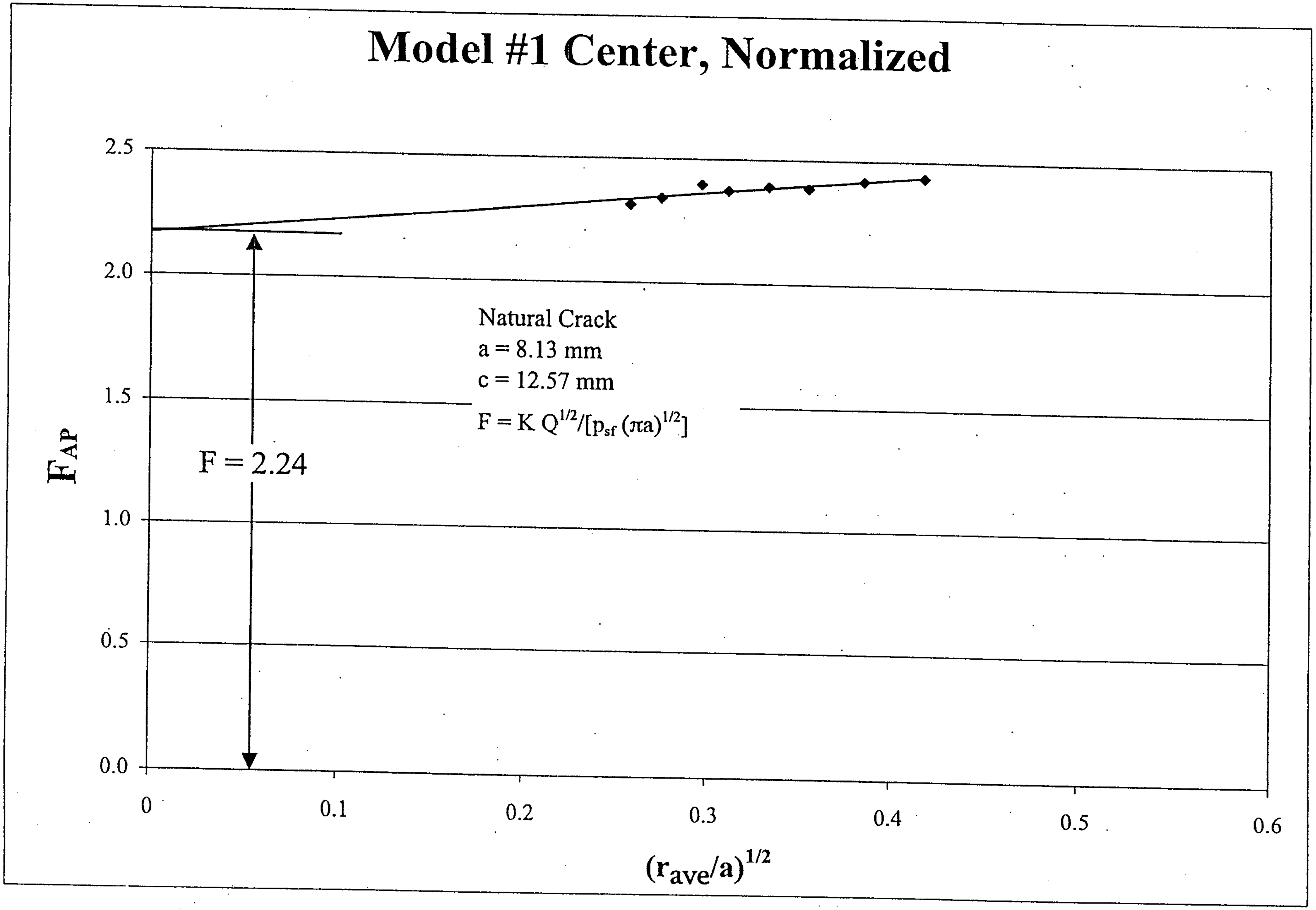


Figure A-3: Determination of Normalized Stress Intensity Factor (F) from Test Data.

Table 1

Test Data and Computed Results

Col	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Test	a	c	a/c	a/t	ρ_{sf}	ρ_{max}	K_{EXP}	K_{GKD}	K_{BF}	K_{PSE}	F_{GKD}	F_{BF}	F_{EXP}	F_{PSE}
1	8.13	12.57	0.65	0.22	0.041	0.121	0.35	0.37	0.57	0.55	2.34	2.77	2.24	2.65
2	14.6	23.00	0.63	0.39	0.046	0.129	0.47	0.54	0.93	0.82	2.25	2.99	1.98	2.63
3*	19.6	32.50	0.60	0.53	0.028	0.167	0.33	0.39	0.70	0.60	2.27	3.17	1.94	2.71
4	8.31	183.24	0.05	0.22	0.041	0.041	0.46	0.56	0.58	0.48	2.70	2.77	2.22^{+}	2.28
5	14.6	181.65	0.08	0.39	0.041	0.041	0.68	0.73	0.83	0.78	2.65	2.99	2.49^{+}	2.81
6	19.6	175.30	0.11	0.53	0.023	0.023	0.44	0.48	0.57	0.52	2.70	3.17	2.47^{+}	2.90

Linear dimensions -mm

Pressure = N/mm^2

$$F = \frac{K_1\sqrt{Q}}{pR_i/t)\sqrt{\pi a}} : \sqrt{Q} = \phi = \text{elliptic Integral of 2nd kind}$$

K values = $\frac{N}{mm^{3/2}}$

R_i = Inner cylinder radius $Q \approx 1 + 1.464\left(\frac{a}{c}\right)^{1.65} \quad \frac{a}{c} < 1$

ρ_{sf} = Stress freezing pressure $\quad t$ = Cylinder wall thickness or (distance from fin tip to outer boundary)

<u>subscript notations</u>

KGD = Gouzhong, Kangda and Dongdi (For Cyl.)

BF = Bowie & Freese (for Cyl.)

$$K_{PSE} = K_{EXP}\left(\frac{K_{BF}}{K_{GKD}}\right)$$

+ These crack shapes were <u>not</u> semi-elliptical or through the length cracks.

* Cylinder length was 336mm

Summary

By capitalizing on observed similarities between the cracked finned model and a cracked cylinder when placing the fin tip at the inner edge of the cylinder, estimates were made by assuming a plane strain solution for the finned model in finite length models. Based upon the aforementioned limited results, use of a modified plane strain solution appears to yield a slightly conservative prediction for long shallow cracks to significantly conservative prediction for deep part-through cracks.